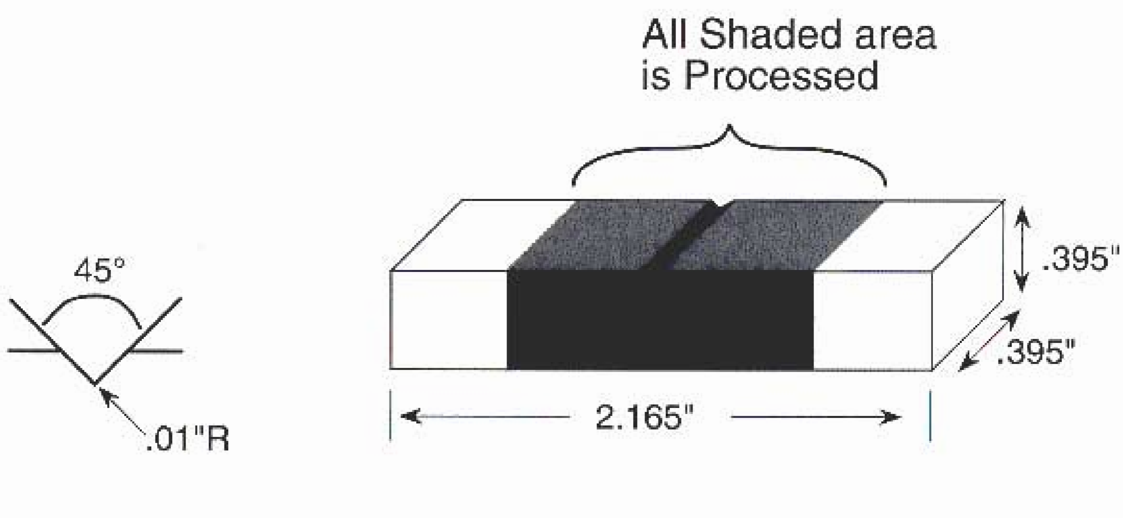
Badger Metal Tech, Inc.

MetalLife®

COMPRESSIVE STRESS TEXTURING

CHARPY IMPACT LAB TEST



EDM EFFECTS ON H13 STEEL

IN our last test brochure, we discussed the value of applying MetalLife. to a ground surface (see H-13 Thermal Stress Lab Test) to reduce thermal stress cracking (heat checking). Since that time, Case Western Reserve University has completed another test that measures the Charpy impact strength of Electric-Discharge Machined (EDM) H-13 after additional surface treatments have been applied. These treatments included mechanical, chemical, and thermal methods. One of these tests involved MetalLife. since it is the approved mechanical method of surface treating tools. Again MetalLife. showed significant benefits. Table "A" gives a listing of all the surface treatments that were tested. Melonite is a non-toxic form of Tufftriding. Case Western chose these surface treatments based on earlier results from H-13 Thermal Stress Tests.

TREATMENTS	COMMENTS
Nitrotec	Proprietary Gaseous Nitrocarburizing
Ion Nitriding	975°F, 24 hrs.
Melonite and QPQ	Proprietary Liquid Salt Bath Nitriding
MetalLife.	Proprietary Surface Impaction
Electropolishing	Amps: 150 Volts: 9 Solution: 41% Sulfuric Acid 45% Phosphoric Acid 7% Chromium Trioxide 17% Distilled Water

Table A

EDM CHARACTERISTICS

Electrical-Discharge Machining offers a relatively inexpensive means of producing die cast dies. The process is capable of producing intricate details and is independent of the hardness of the tool steel. Quite often Electrical-Discharge Machining (EDM) eliminates the need for secondary finishing operations. Unfortunately, at the same time, the thermal fatigue resistance is significantly reduced over that of a conventional machined die. This detrimental influence is attributed to the damaged layers on the surface of the tool consisting of a brittle white recast layer, a hardened layer, and softer untempered region. In addition, high detrimental residual tensile stresses are generated.

Since metal is removed by a series of electrical spark discharges, the steel in the contact area melts or vaporizes then solidifies very rapidly. Some of this melted material solidifies on the surface of the cavity. Each spark erodes a small bit of metal, leaving a small crater in the surface of the tool. This leaves the surface in a high residual stress condition which can lead to early heat checking and gross cracking.

The size of this crater is determined by factors such as: length of current flow time, duty cycle, gap voltage, and discharge current. Pulses of ON time should be of equal length and always greater than the OFF time. A higher direct current voltage creates a current spark discharge across a wider gap. Higher current flow (amperes) produces higher rates of removal of metal. The resulting surface pattern on an EDM surface is a series of small overlapping craters. The surface roughness, which is related to the crater size, increases with increasing spark energy. Better metal conductivity of the workpiece material enhances the metal removal rate and makes the surface rougher. It is this surface roughness and the melted and solidified surface which, if not attended to, can lead to serious die problems.

EDM LAYERS

Figure "1" shows the different layers resulting from EDM. The recast layer is a brittle, non-etchable white layer containing cracks. This is the material that has melted and rapidly solidified and is not flushed away by the dielectric fluid. This layer is densely infiltrated with carbon and has a distinct separate structure to that of the parent metal. The thermal contraction of the resolidified material or recast layer onto the relatively unaffected base metal induces plastic deformation and tensile stresses that have been measured to approach the yield strength of the material. The cracks are caused by these high tensile residual stresses that exceed the ultimate strength of the material. The thickness of the white layer is determined by the efficiency of heat transfer through the rapidly solidifying metal. This layer must be removed by polishing prior to any use of the die.

The next layer, the heat affected zone, is the base steel that has been structurally altered by the heat produced during EDM. The high temperature produced by the EDM process has reached the austenizing temperature range. This zone may contain rehardened or hard, brittle untempered martensite which is formed during the rapid cooling from this temperature. This can be expected to increase crack susceptibility since this microstructure stores considerable strain energy that decomposes with heat.

Below this layer, the temperatures attained are not as high and tempering below the original hardness occurs. This layer is then softer than The 44 - 48Rc range of the original H-13 surface.

The relative depth and even the presence of these layers is dependent on what type of EDM methods are used. The thickness of both the recast and rehardened layer increases with spark duration. This appears to be the

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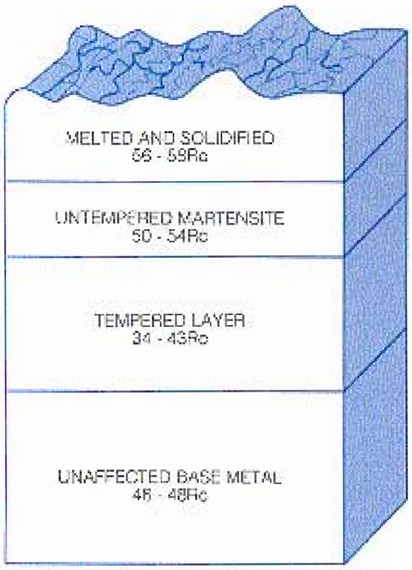

Typical Depth (microns)	Actual E2	Actual E5
8 - 25	3.8	23
25 - 40	*	33
40 - 85	85.9	76

* could not be measured

Figure 1: Typical Example of the Various Layers in an EDM Machined Surface of H-13 Die Steel

most important controlling variable. With longer pulse durations, the heat is conducted more deeply into the material. The recast white layer and softened layer appear to always be present, however, the presence of the untempered martensite is dependent on the EDM treatment.

EDM surfaces are consequently very hard and textured. The higher hardness can improve the abrasive resistance of the material, however, the existence of residual stress reduces the fatigue resistance of the die to heat checking and gross cracking. Grit polishing of a surface that has a very thin recast layer will convert some residual stress to compressive stress but will not close existing cracks. Research has shown that the permanent surface damage, such as microcracks, has a greater influence on the reduction of fatigue life than does the presence of high residual stress at the surface. Tempering of the rough EDM'd surface does not eliminate cracks but does render the white recast layer less brittle. MetaLLife. **compressive stress texturing closes the cracks that have propagated below the recast layer and restores the desired residual compressive stress benefits.**

MODES OF DIE FAILURE

Before we discuss the actual Charpy test parameters, it would be good to review the types of failure modes of die casting dies. These include mechanical erosion, chemical attack or corrosion, heat checking also referred to as thermal fatigue cracking, and the most severe: gross or cleavage cracking which leads to total failure of the tool.

Two types of mechanical erosion have been defined. One is wear erosion caused by the high velocity of the molten metal as it enters the die. This is most frequent at gating locations. The other is cavitation erosion that is the result of the collapse of gas bubbles in the molten alloy near the surface which cause high pressures at the surface and contributes to the mechanical fatigue and adds to thermally induced fatigue. For these reasons the MetaLLife. process always includes the runner gate area of the insert. The texturing to this surface helps to reduce the mechanical erosion characteristics by slowing down the high velocity of the molten metal. The turbulent effect of the textured surface also tends to break up the entrapped gases into smaller units that reduces the pressures on the die surface.

Chemical attack can occur through decarburization and oxidation or corrosion of the die. Compositional changes in the die alloy degrade the strength and ductility of the die surface which create oxides and results in accelerated thermal fatigue. This leads to early heat checking. Because oxides occupy a larger volume than the metal that was previously present, a wedging action occurs which contributes to further crack propagation. Another form of chemical attack is chemical adhesion or soldering of the cast metal to the die surface which causes damage to the die steel as well as the casting. MetaLLife. is a mechanical contact process which removes the surface oxides and closes the resultant wedge cracks that may have started on the die surface. The surface is hence encapsulated in a beneficial layer of compressive stress. The textured surface retains lubricant more efficiently which helps reduce future soldering. This texturing resulting from the compressive stress is beneficial whereas the texturing resulting from EDM is detrimental.

Heat checking is perhaps the most frequent cause of failure. Sooner or later, heat checking will appear in every die no matter what steel is used or what surface treatment has been applied. It is almost universally accepted that thermal fatigue is caused by the constant heating and cooling of a die during the die casting operation. When these stresses exceed the material elastic limit or yield strength, the steel surface can upset and the repeated heating and cooling of the die will generate a fine network of cracks on the die surface. Cracks initiate and propagate in both an intra- and inter-granular manner and are filled with oxides which contribute to the wedging action and allow the cracks to further propagate. Tests previously conducted at Case Western and continuing field reports, confirm that the compressive stress benefits of MetaLLife. significantly retards this phenomenon not only on **USED** but also **NEW** dies as well.

Unlike the other failure modes, gross cracking is not as directly related to the surface of the die cavities. While it does not occur as frequently, it is far more serious and can result in the complete cracking of a die. Usually this will require that the die be replaced. The physical mechanism for this is the unstable propagation of a brittle crack under tensile stress conditions. A combination of thermal and mechanical stresses cause gross cracking. Stress

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The formation of these indentations yields the surface fibers of the material in tension. Below the surface, the fibers try to restore the surface to its original shape and thereby create a cold worked material highly stressed in compression. The rigid controls allow the overlapping dimples to develop an even layer of residual compressive stress. Since tension is usually the stress that produces cracking in steel, this opposing compressive stress layer which is in the range of 50% of the materials effective yield strength, prevents cracks from propagating.

The Charpy V-notch impact test results at room temperature for all surface treatments tested is shown in Figure 2. This test measures the amount of energy that is needed to break the sample V-notch bar. In general, the impact resistance and fracture toughness or gross cracking resistance are inversely proportional to the hardness. Lower toughness is attributed to high hardness at the surface. It has been found that Charpy values exceeding 15 joules (11 ft-lbs) are desirable in practical die casting. The low temperature surface treatments tested, such as Nitrotec, ion nitriding, and Melonite (a non-toxic form of Tufftriding) had only a range of 2.5 to 7 ft-lbs with an average of 3 to 4.4 ft.-lbs. This is significantly lower than the tested conventionally machined and ground notch specimen that exhibited an average of 12.5 ft. lbs.

As expected all of the MetaLLite. samples for both the E2 and E5 EDM methods, whether or not polished and/or tempered afterwards, showed a higher impact energy than that of the ground surface or low temperature surface treatments. For undetermined reasons there was somewhat less of an improvement on the high intensity (H.I.M) E2 samples that had been tempered (T) and polished (P). Electropolishing also showed an increase in impact strength but not as much as the MetaLLite. samples.

CONCLUSIONS

Previous testing of H-l3 materials has shown that dies receiving the MetaLLite. process have a much greater resistance to heat checking and thermal fatigue This is true whether it be applied to a NEW or USED tool. This test now confirms that,in the case of EDM H-13 material, the resistance to gross cracking is also increased by the application of MetaLLite. . These average increases in impact energy were found to be anywhere from 23.2% to 39.2% greater than that for a machined and ground surface. The poor thermal fatigue resistance of the ion nitriding and Nitrotec treatments is attributed to the brittleness of the compound zone consisting of FE4N/FE2N3 in the ion nitrided sample and FE3N in the Nitrotec sample. The Melonite sample also had significantly reduced Charpy impact strength.

If the die caster desires resistance to gross cracking and increased resistance to fatigue cracking, MetaLLite. is still the most effective surface treatment to apply to EDM or milled/ground surfaces. In addition, none of the other surface treatments have the ability to close existing cracks in die surfaces to keep them from further propagating. The die caster therefore has two choices for longer die life: he can *PREVENT IT NOW - to extend his new tool life, or RESTORE IT LATER* - to obtain additional life from dies that are already heat checked.

FUTURE TESTS

In the next phase of testing, Case Western will look at what effect multiple surface treatments may have to increasing die life and their relation to thermal fatigue and Charpy impact strength. In addition Ohio State is conducting testing on the erosion, soldering, and flow qualities of a MetaLLite. surface. Results of these tests will be published when testing is completed and reports are available. Please call us if you have any questions regarding this test or other aspects of the MetaLLite. process. Our Toll Free Number is on the back of this brochure.

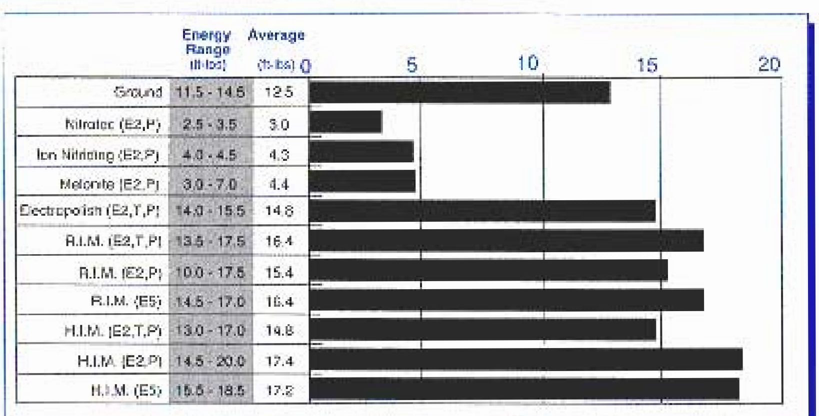

Figure 2. CHARPY V-NOTCH AVERAGE IMPACT ENERGY (FT-LBS)

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